

# Jet Physics at CDF

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# Outline

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- CDF Run II and new opportunities
- Run II inclusive jet cross-section
  - Current measurement
  - Leading uncertainties
  - Further improvements
- Understanding fragmentation:
  - Quark and gluon jet differences
    - Multiplicity and Momentum Distributions
    - Comparison to NLLA predictions
    - MC and data comparisons
- Summary

# CDF Detector Run II Upgrades

All critical components are working well

7-8 silicon layers  
 $r\phi$ ,  $rz$ , stereo views  
 $z_0^{\max}=45$ ,  $\eta^{\max}=2$   
 $2 < R < 30\text{cm}$

132 ns front end  
COT tracks @L1  
SVX tracks @L2  
40000/300/70 Hz  
~no dead time

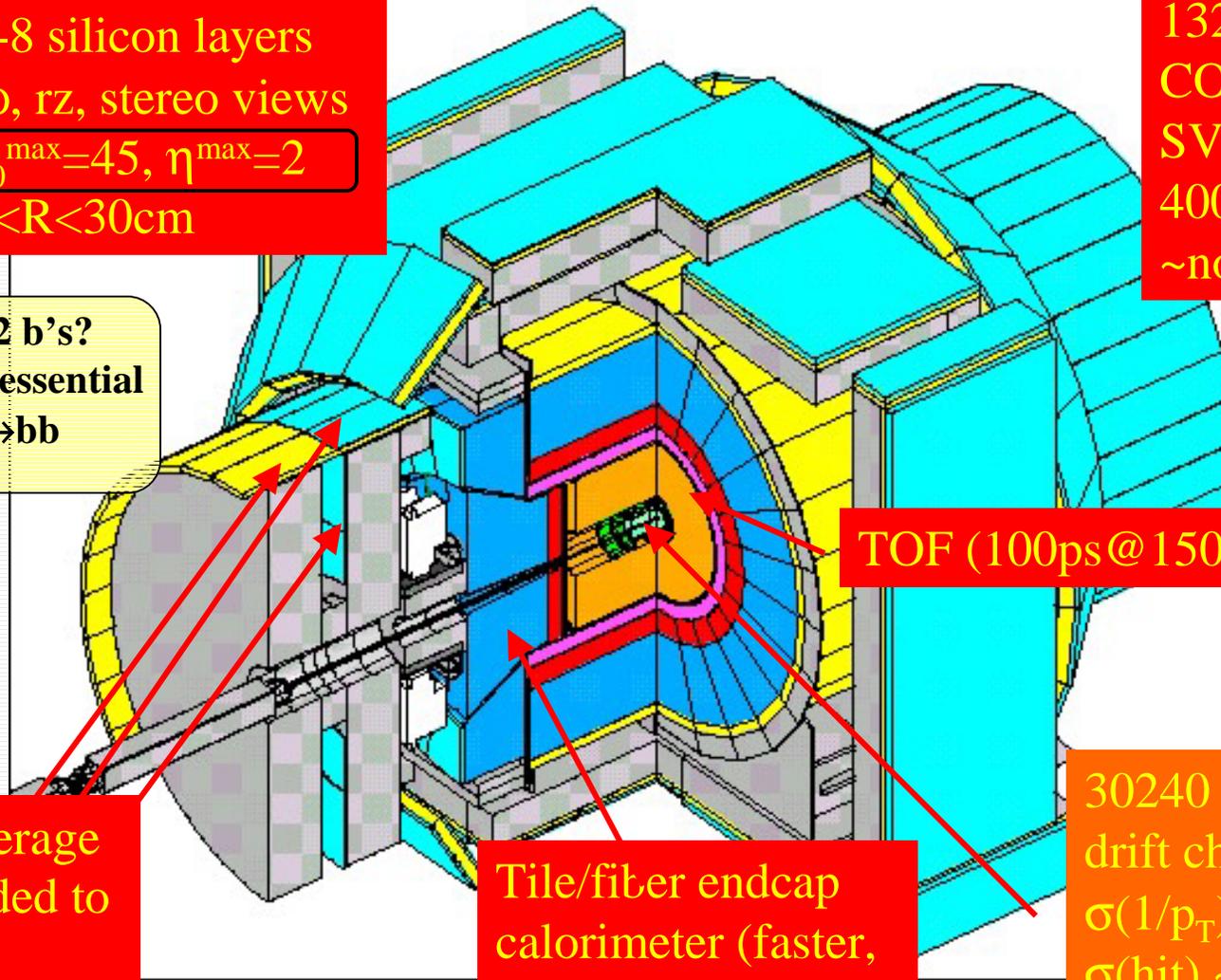
2 b's or not 2 b's?  
Double tags essential  
for  $M_{\text{top}}$ ,  $H \rightarrow b\bar{b}$

TOF (100ps @ 150cm)

$\mu$  coverage  
extended to  
 $\eta=1.5$

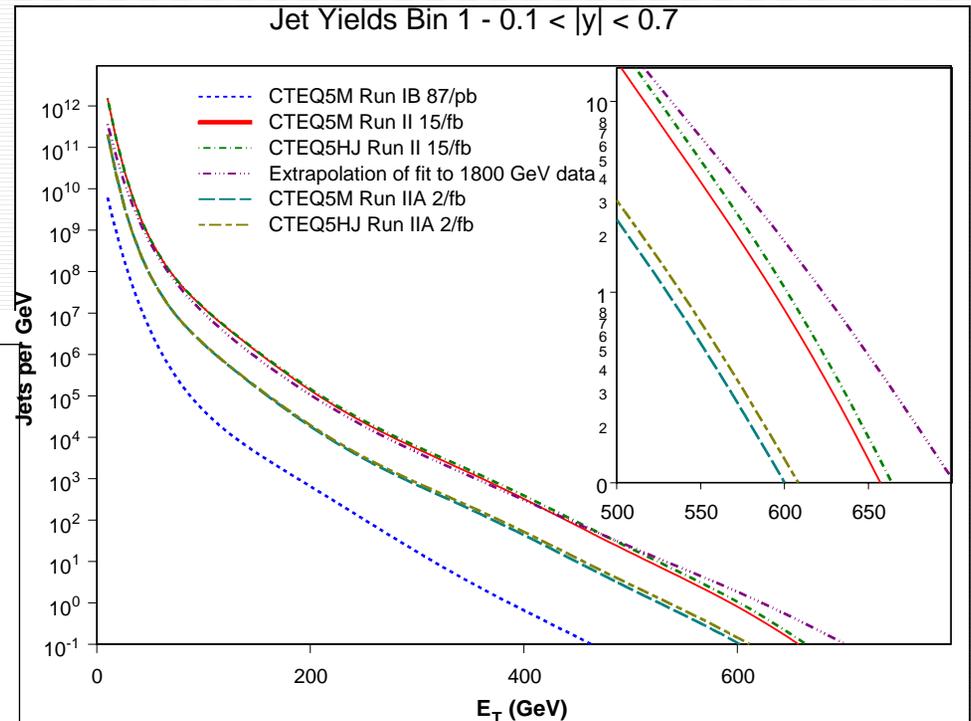
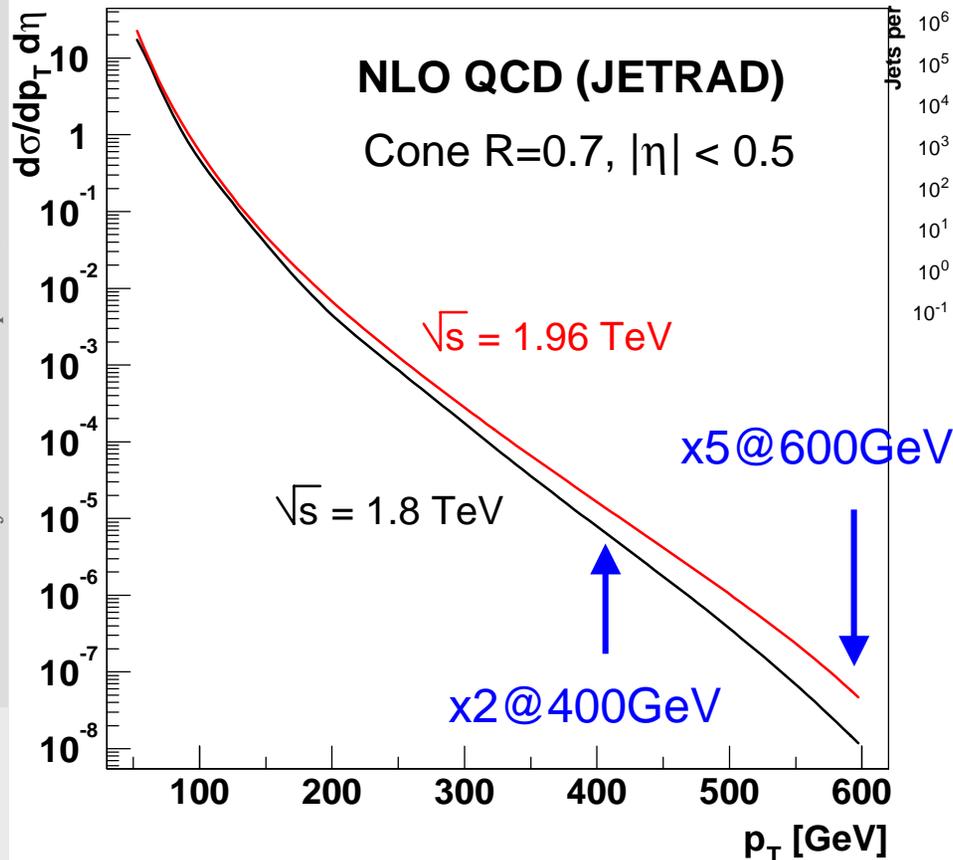
Tile/fiber endcap  
calorimeter (faster,  
larger  $F_{\text{samp}}$ , no gap)

30240 chnl, 96 layer  
drift chamber  
 $\sigma(1/p_T) \sim 0.1\%/GeV$   
 $\sigma(\text{hit}) \sim 150\mu\text{m}$

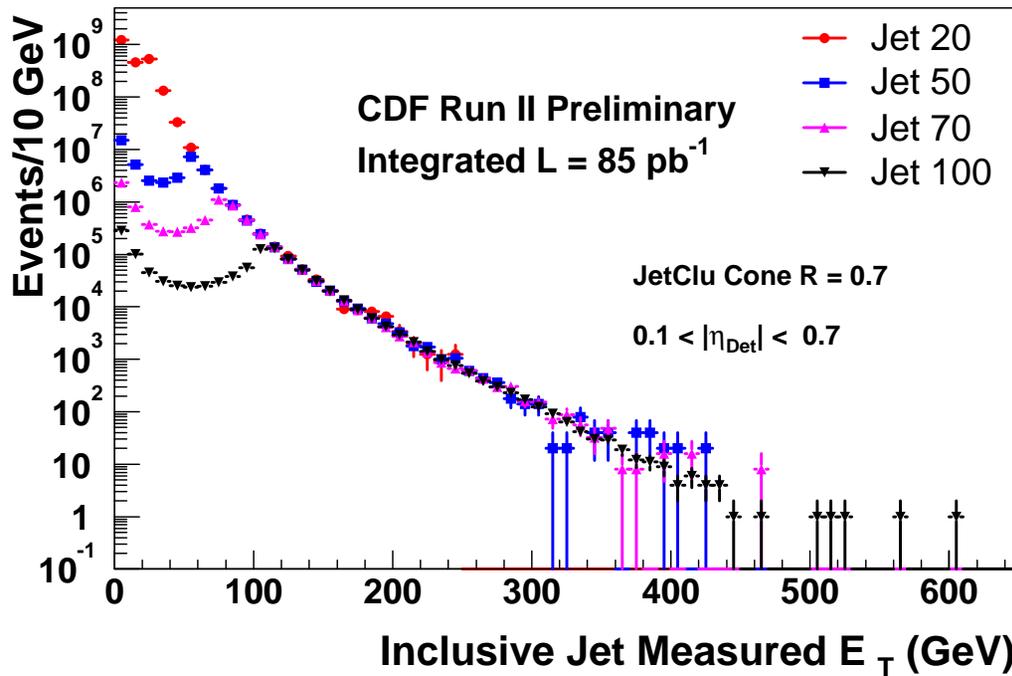


# Jet Production at the Tevatron

- Nowhere else the increase in center of mass energy is appreciated so much



# Jet Triggers at CDF



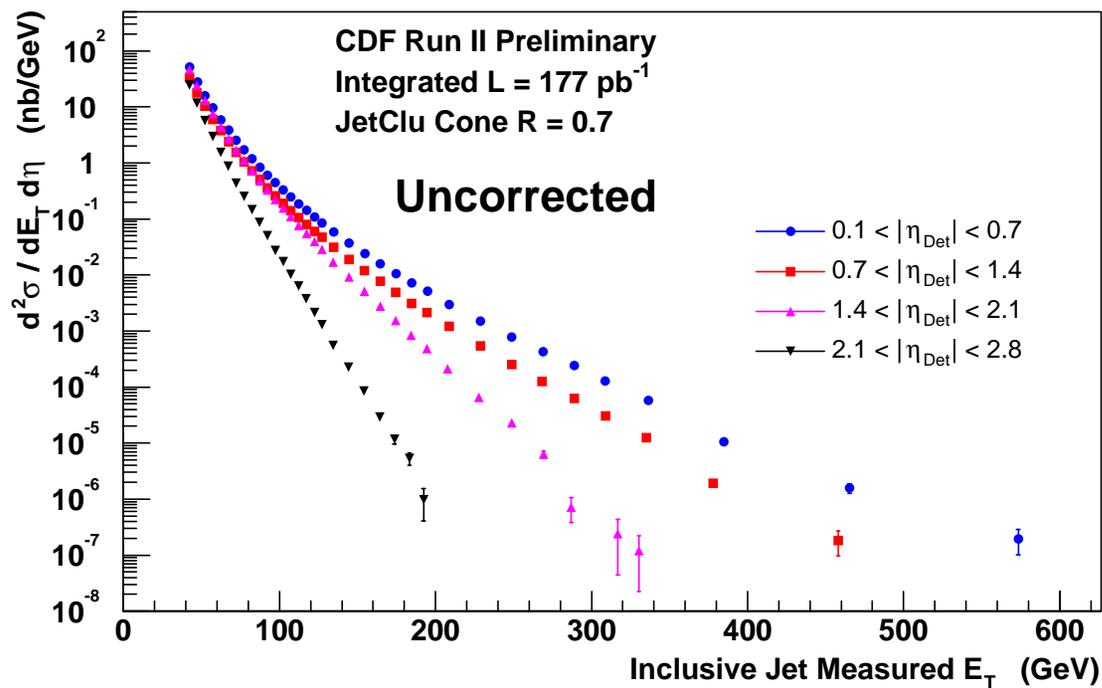
## 3-Level Trigger System:

- L1: Trigger Tower E<sub>T</sub>
- L2: Continuous Clusters
- L3: Cone Algorithm

## Trigger Specs/Prescales

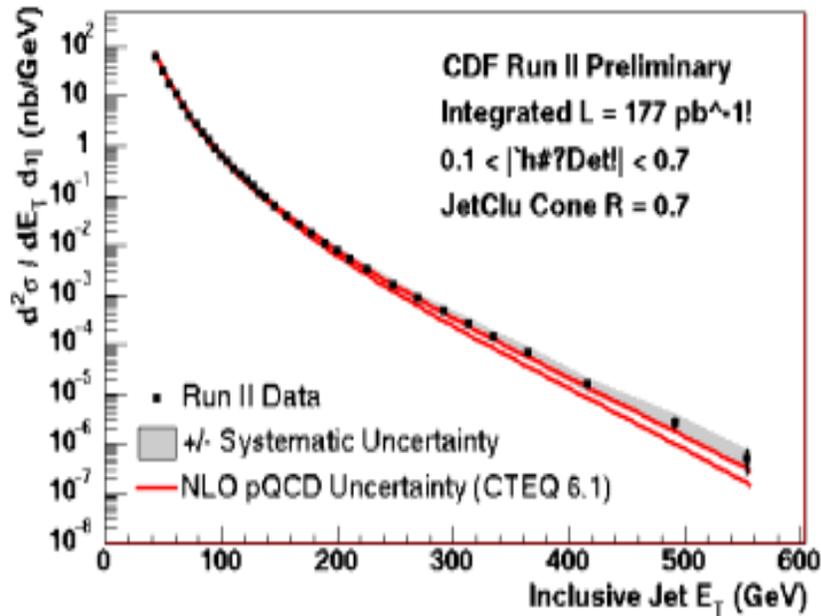
Trigger	L1	L2	L3
JET 20	ST5 (20)	CL15 (12,25)	J20 (1)
JET 50		CL40 (1)	J50 (1)
JET 70	ST10 (1)	CL60 (8)	J70 (1)
JET 100		CL90 (1)	J100 (1)

# Raw Inclusive $E_T$ Spectrum

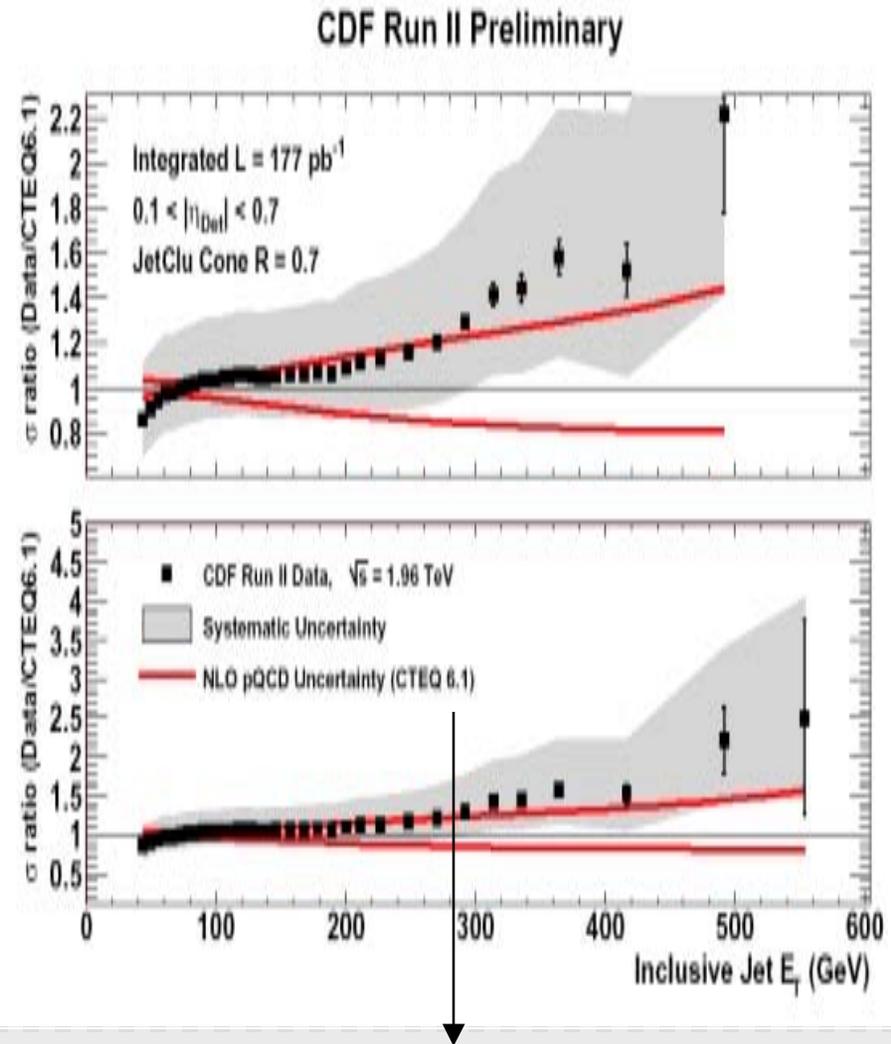


- Usable jets up to  $\eta \sim 2.8$
- Jet energy corrections are not applied
  - $E/P \sim 60\%$  for charged hadrons

# Run II Central Jet Cross Section

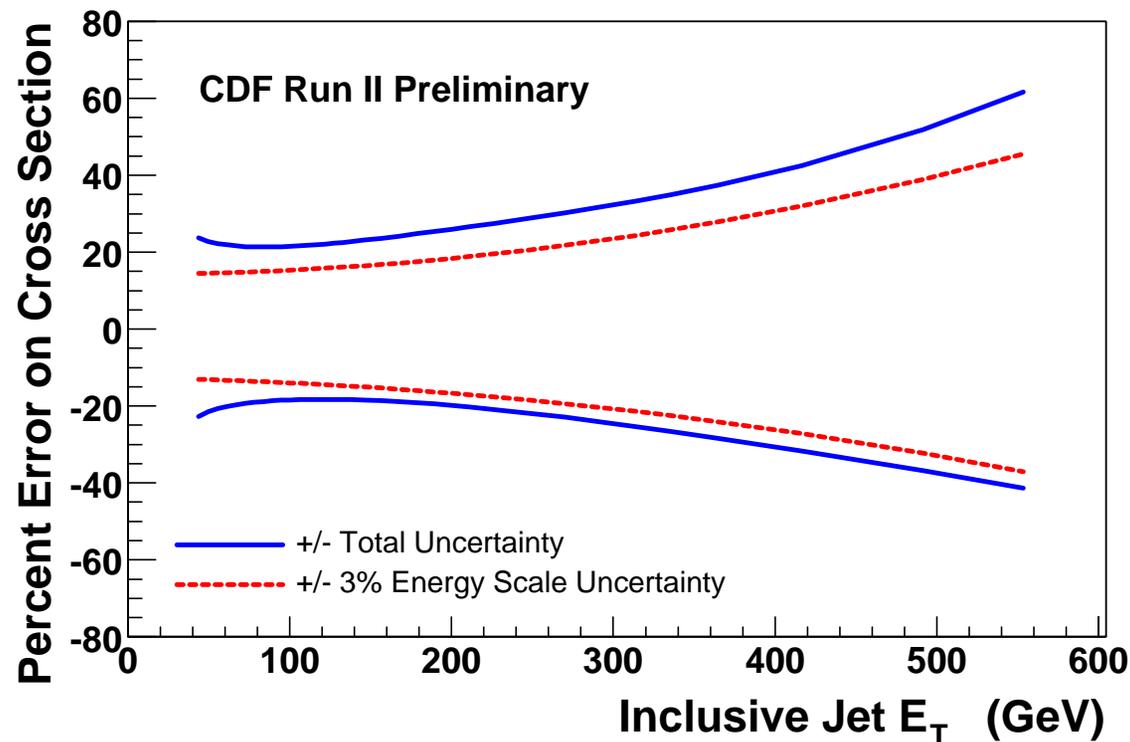


- Jet cross section in agreement with theoretical prediction within errors
- Dominant theoretical error is due to PDF uncertainty



CTEQ6.1 already has an enhanced high  $x$  gluon due to influence of Run 1 jet data

# Systematic Uncertainties

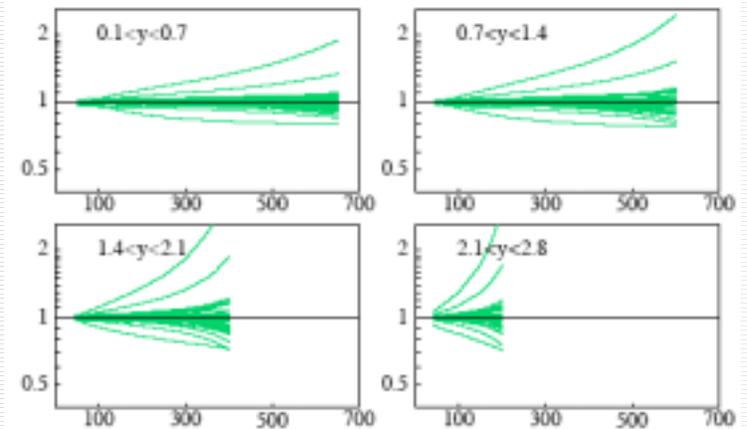
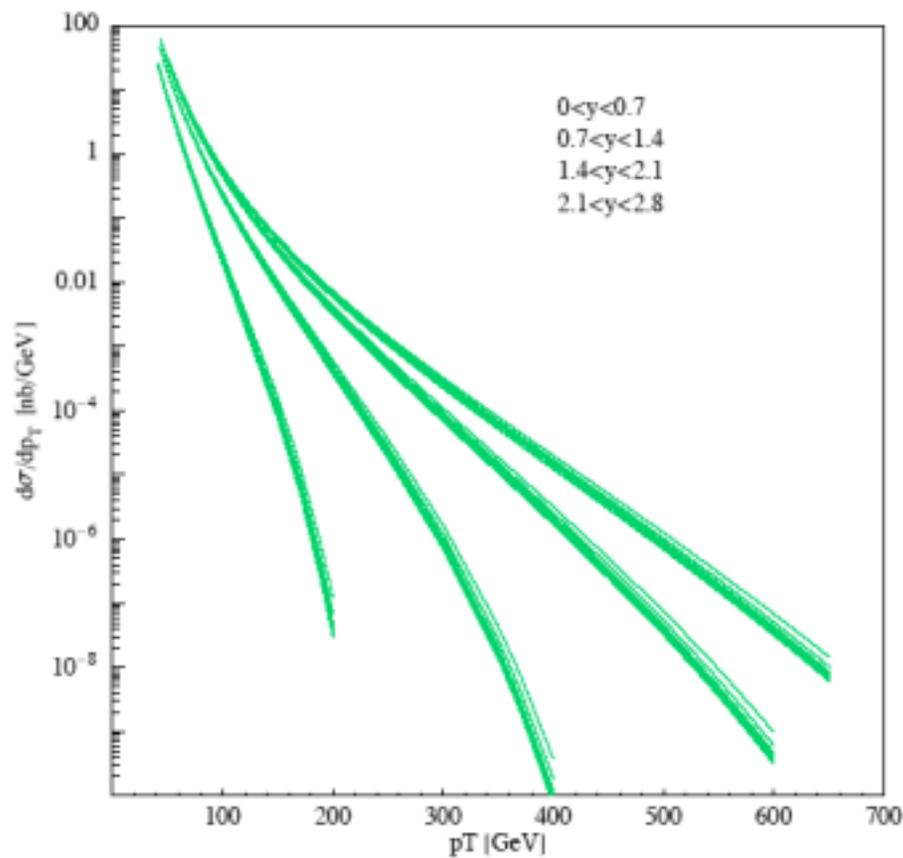


- Energy scale is by far the dominant uncertainty:
  - Currently at 3% level, but exponentially falling shape of the ET spectrum results in a large effect
  - Goal is ~1%

- Next-to-leading uncertainties:
  - High ET response
  - Fragmentation

# Sensitivity to PDF

- Jet cross section in the forward region – work in progress

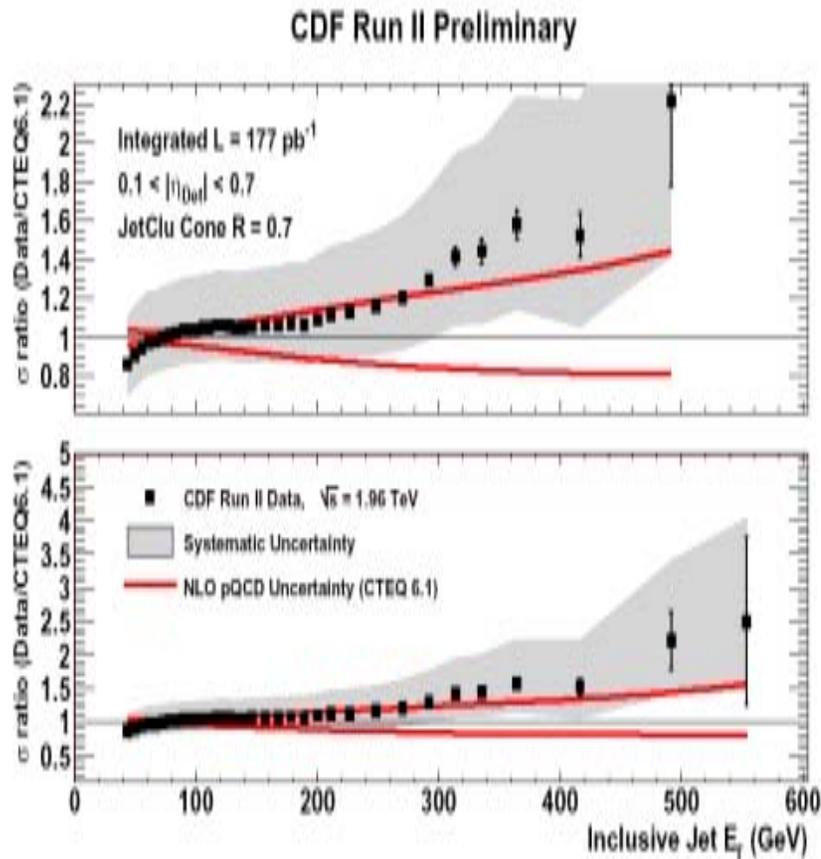


\*) Uncertainty range of the Run 2 cross section for the CDF rapidity bins, ratios of the 40 eigenvector basis sets compared to the central (CTEQ6.1N)

- Forward regions are highly sensitive to PDFs
  - New Physics is primarily central
  - PDF explanation should work everywhere else
  - Accurate measurement will help constraining PDFs

# Looking forward to NNLO

- Further data/study will reduce the PDF uncertainty



## Why go beyond NLO? (1)

- Better estimate of size of cross section
  - LO  $\Rightarrow$  order of magnitude estimate ( $\mu?$ )
  - NLO  $\Rightarrow$  reliable estimate of  $\sigma$  ( $\Delta\mu?$ )
  - NNLO  $\Rightarrow$  reliable estimate of  $\Delta\sigma$

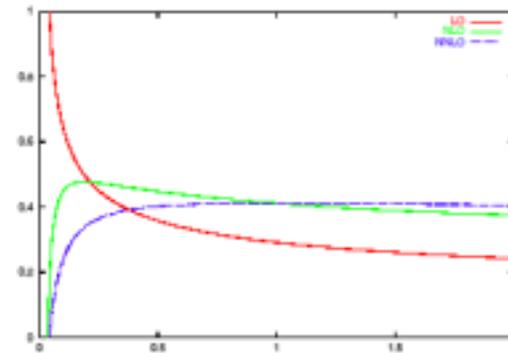


Figure 1: Jet cross section  $d\sigma/dE_T$  for  $E_T = 100$  GeV versus renormalisation scale  $\mu/E_T$ . NNLO is the renormalisation group predictable part. We see that for renormalisation scales within a factor of two of the jet energy, the renormalisation scale uncertainty is reduced from 20% to 9% to 1%.

Need NNLO jet cross section for useful NNLO PDF's to be determined

# Why Fragmentation?

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- Experimental studies of fragmentation test our understanding of QCD, especially at the difficult region of low momentum transfer
- Uncertainty for other QCD studies and new physics searches
  - Improved knowledge will lead to better constraints of SM parameters and new physics
- What can be done:
  - Momentum distributions
  - Track multiplicities
  - Charged/neutral particle fractions
  - Differences of quark and gluon jets

# Quark and Gluon Jets

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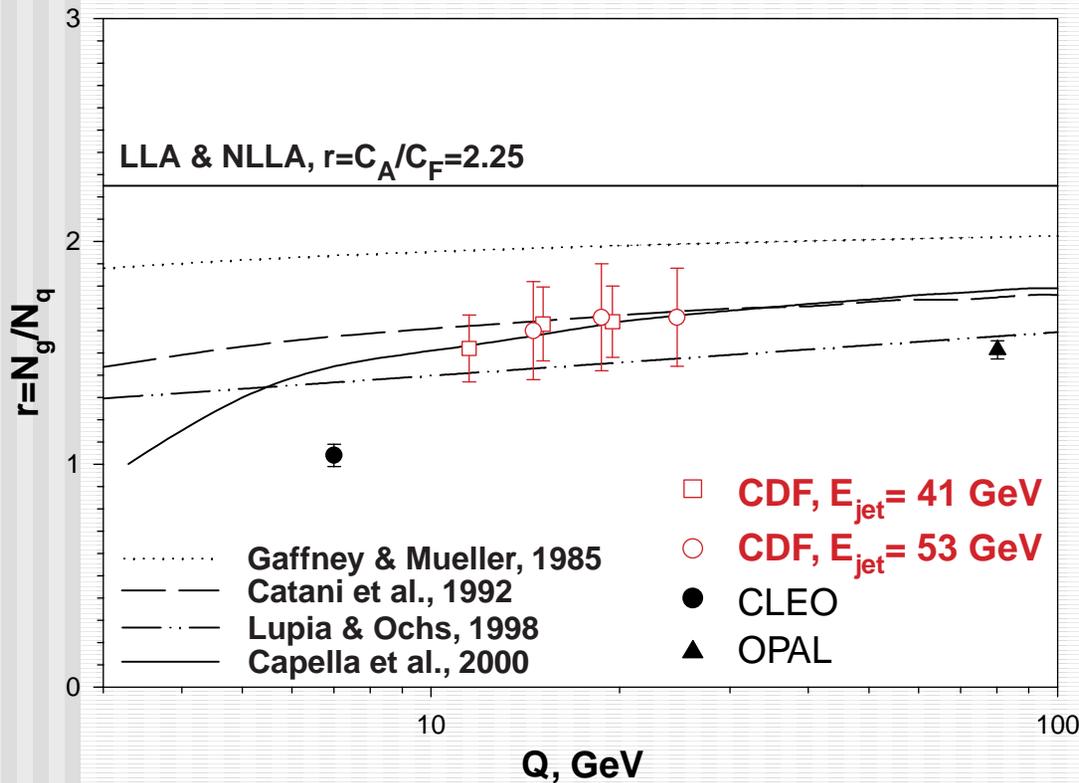
- Historically, proved to be a difficult experimental issue:
  - Many past measurements disagreed with each other
  - Comparisons to theory were often at best controversial (and many eventually incorrect).
- Fragmentation studies at hadron colliders:
  - Obvious difficulties: from underlying event debris to conventional wisdom
  - Important advantage: quark and gluon jets are easy to find in our environment (no need to look for events of complicated topology that can bring biases)

# CDF Measurement: Outline

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- Theory side: MLLA-inspired NLLA calculations:
  - Track Multiplicity and Momentum Distribution of quark and gluon jets
- Experimental measurement:
  - Model-independent measurement requires two samples with known fractions of q/g jets
  - Jet-jet vs  $\gamma$ +jet data is one example
  - Properties of q and g jets can be statistically disentangled
  - Compare to theory and available MC

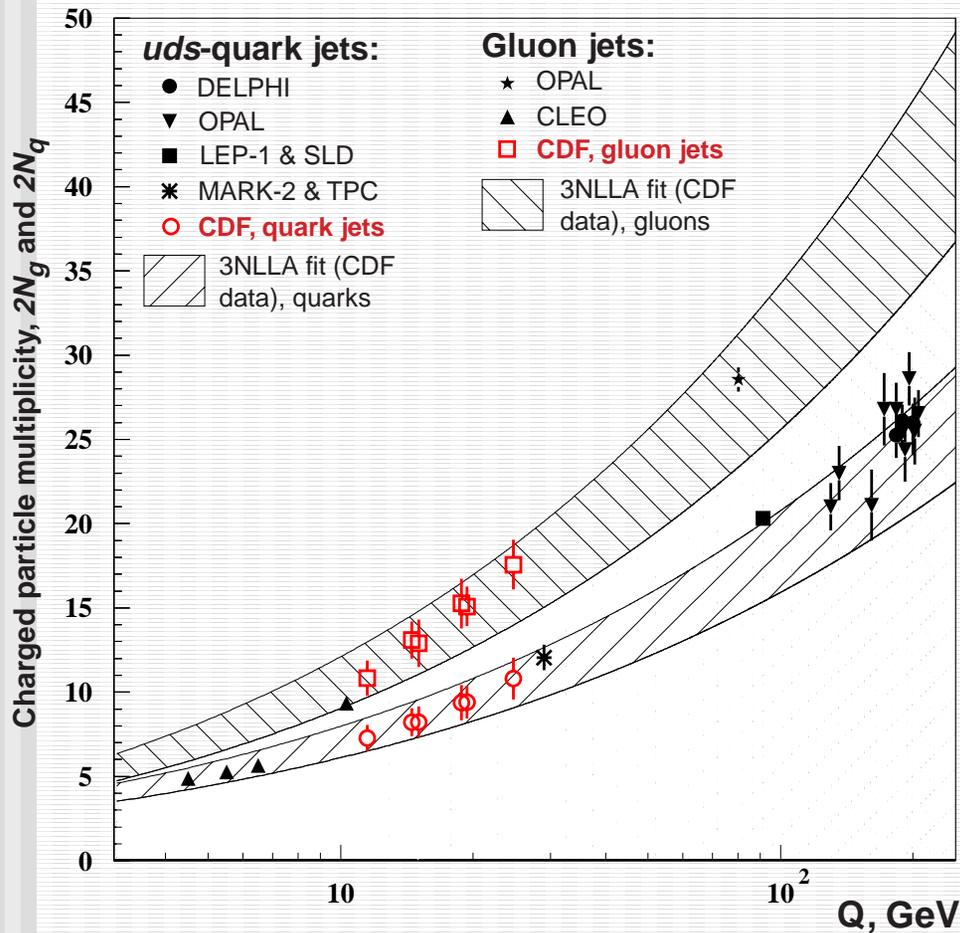
# Ratio of Track Multiplicities



$$Q = E_{jet} \sin(\theta)$$

- Track multiplicities measured in cones ( $\theta$ ) around the jet axis
- Good agreement with NLLA predictions
- Given uncertainties, hard to compare with OPAL
- Poor agreement with MC:  $\sim 1.3$  for both Herwig and Pythia

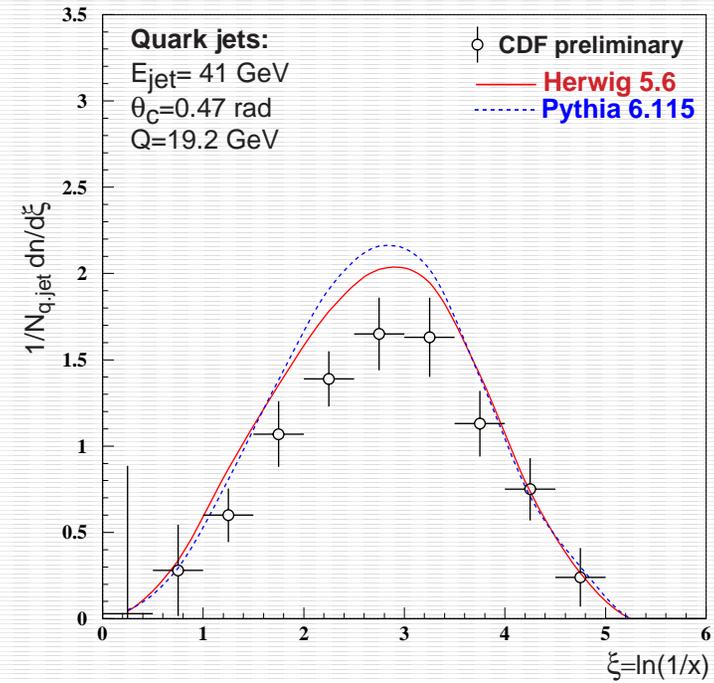
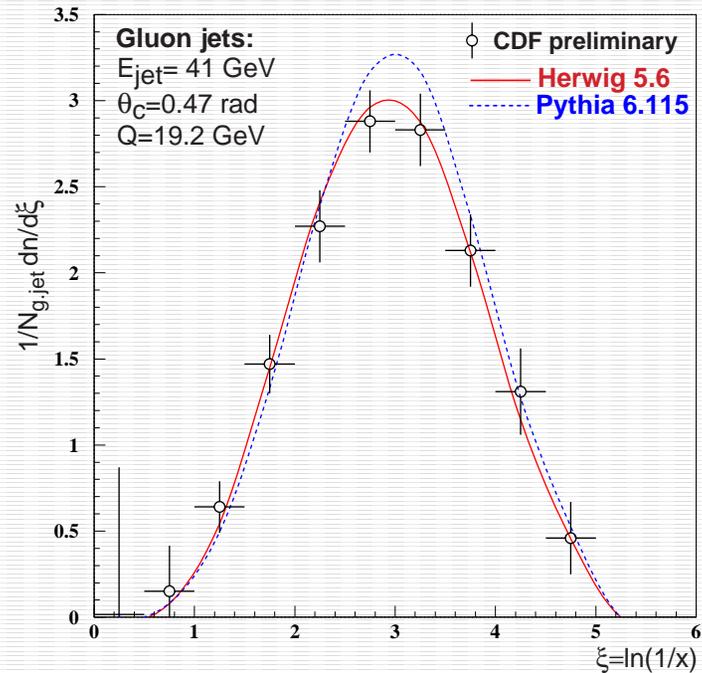
# Track Multiplicity in q/g Jets



- Fit of CDF only Data to NLLA prediction (A. Capella et al.)
- Good agreement with theory and most of recent experimental results
- MC overestimates track multiplicity for quark jets (both Herwig and Pythia)

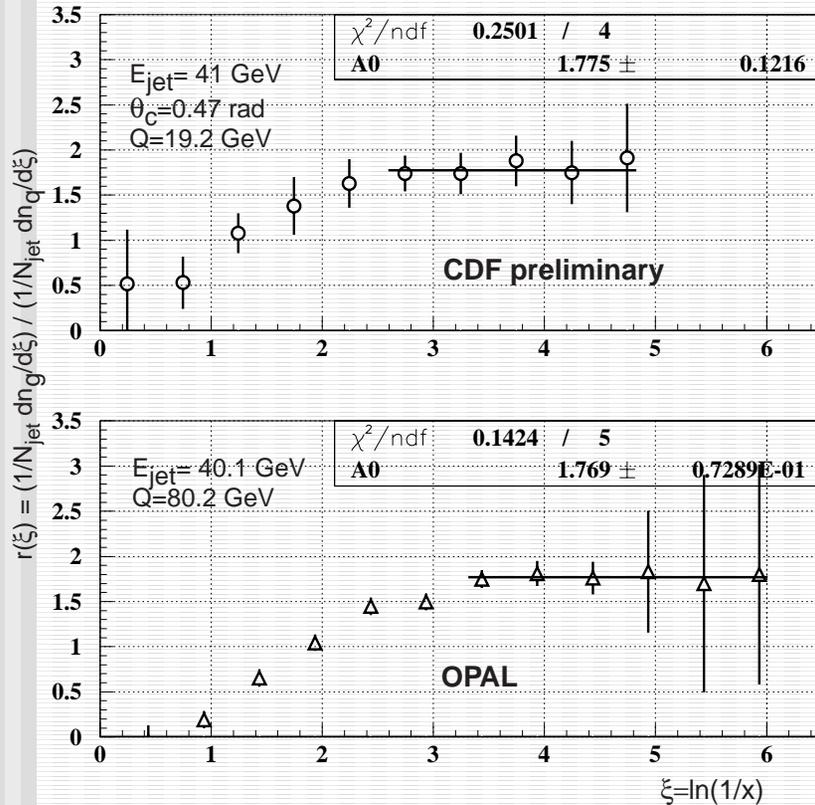
$$Q = E_{jet} \sin(\theta)$$

# Momentum Distributions



- Compare momentum distributions to Herwig and Pythia
  - vs MLLA variable  $\xi = \log(1/x)$
- MC overestimates track multiplicity in quark jets

# Soft Limit of 9/4



- MLLA: soft limit can still be reached for soft partons emitted at large angles
- Ratio of track momentum distributions from CDF and OPAL (similar  $E_{\text{jet}}$ ,  $Q$ -scales are different):
  - Plateau in the soft part
  - Not 9/4 due to hadronization effects (angles are not necessarily large), but similarities are quite clear

# Conclusions

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- By now, we more than doubled the luminosity compared to Run I
- Jet production:
  - Greatly improved access to higher ET domain (higher CM energy)
  - Inclusive Cross-Section agrees with NLO
  - Improvements to systematics are in the works
  - Expect further constraints on PDFs
- Quark/gluon jets:
  - Good agreement with NLLA
  - Herwig and Pythia MC need adjustment
- Stay tuned!